

## POTASSIUM CHANNEL OPENER

This application is a continuation-in-part of PCT/JP02/04085, filed April 24, 2002.

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### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to a potassium channel  
10 opener.

#### 2. Background Art

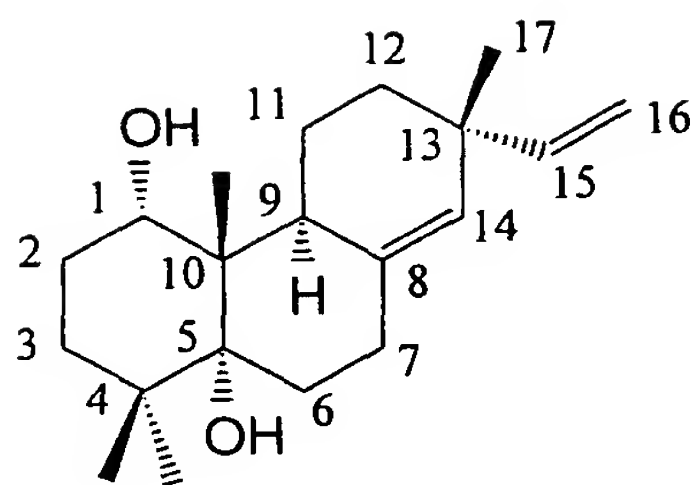
Calcium-activated potassium channel (alternatively referred to as "BK channel") is present on cell membranes and  
15 is a protein which makes potassium ions permeate selectively. This channel protein has a calcium binding domain in an amino acid sequence facing intracellularly, and has a property of enhancing channel activity by binding of calcium. This means, the increase of intracellular calcium concentration leads to  
20 a higher chance of opening of the calcium-activated potassium channel (opening probability), thereby leading to an increase in permeability of cell membrane for potassium. There have been known three kinds of calcium-activated potassium channels, among which large conductance calcium-activated  
25 potassium channels are present in smooth muscles which are constituents of various kinds of organs, including blood vessel, bladder, bronchial tube, gastrointestinal tract, etc., and central or peripheral neuronal cells, however, they are not expressed in cardiac muscles.

30 Membrane potential is dependent on a balance of permeabilities of cell membrane for ions such as sodium, potassium, chloride, calcium, etc. When the potassium channel opening is selectively increased, potassium permeability becomes dominant, and cell is hyperpolarized.  
35 Therefore, opening of the calcium-activated potassium channels, for example, hyperpolarizes smooth muscle cells,

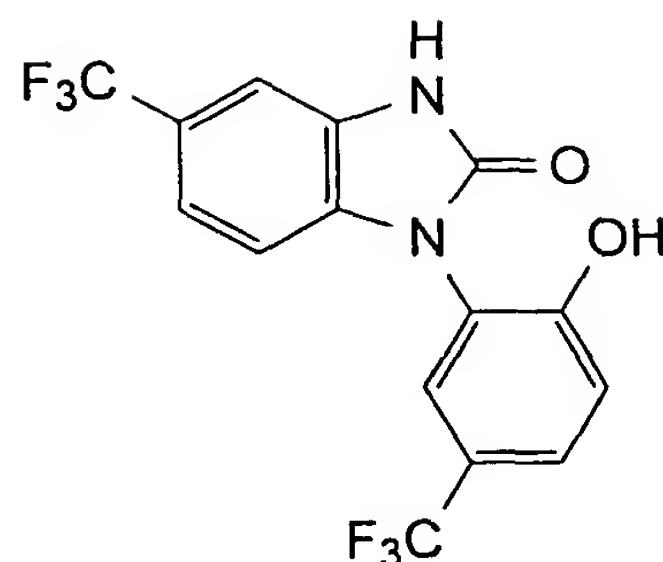
lowers activities of voltage-dependent calcium channels, and inhibits influx of calcium from extracellular fluid. As a result, intracellular concentration of calcium decreases, leading to a relaxation of a smooth muscle. Accordingly, the opening of the calcium-activated potassium channels will make smooth muscle tissues relaxed, which are constantly under contraction (hypertension) in pathological states such as essential hypertension, tonic bladder, airway hyperresponsiveness, etc.

It also exhibits an inhibitory effect on hyperactivity, through hyperpolarization, in neuronal cells whose calcium concentration is increased due to hyperaction (hyperexcitement) caused by a strong stimulus. On the contrary, an administration of a BK channel blocker into central nervous system leads to convulsion in mice. As stated above, since pathological states due to a change in activity of potassium channels including calcium-activated potassium channels have recently become apparent, potential of treatment by potassium channel openers has been increased. Among them, a calcium-activated potassium channel opener is one of those that have been drawing most attention (Shieh, C.C., et al., Pharmacol. Rev., 52, pp.557-593, 2000).

As a substance having effect of activating calcium-activated potassium channels, there have been known maxikdiol (Singh, S., et al., J. Chem. Soc. Perkin. Trans. I, pp.3349-3352, 1994), dehydrosoyasaponin-I (MacManus, O.B., et al., Biochemistry, 32, pp.6128-6133, 1993) and L-735,334 (Lee, S.H., et al., J. Nat. Prod., 58, pp.1822-1828, 1995), which are isolated from natural products, and as synthetic compounds, NS-1619 and its related compounds developed by NeuroSearch of Denmark, and Bristol-Myers Squibb of the United States (Olsen, S.P., et al., European patent publication No. 0477819A2, Olsen, S.P., et al., Euro. J. Pharmacol., 251, pp.53-59, 1994), and the like.



Maxikdiol



NS-1619

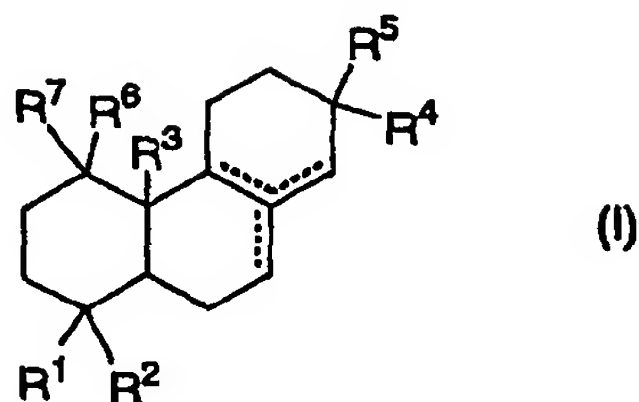
However, dehydrosoyasaponin-I and L-735,334 have relatively high molecular weights, and drawbacks in terms of their functional mechanism. NS-1619 related compounds have low activities, and have a problem that their actions are not specific. Further, although maxikdiol has an excellent activity, it is extremely difficult to obtain, since it is a natural product. Therefore, there have been needs for development of an agent having a BK channel opening activity equivalent to or higher than that of maxikdiol, and having a high specificity of the activity.

#### SUMMARY OF THE INVENTION

The object of the present invention is to provide a potassium channel opener, preferably a calcium-activated potassium channel opener. More specifically, the object of the present invention is to provide a potassium channel opener, preferably a calcium-activated potassium channel opener, which has BK channel opening activity which is equivalent to or higher than that of maxikdiol, and has high specificity of the activity. The present inventors have carried out intensive studies to solve the above stated problems, and as a result, they have found that pimaric acid and its derivatives have extremely excellent potassium channel opening actions, and that these actions are specific. The present invention has been completed based on the above findings.

Accordingly, the present invention provides a potassium

channel opener comprising a compound represented by the following formula (I):

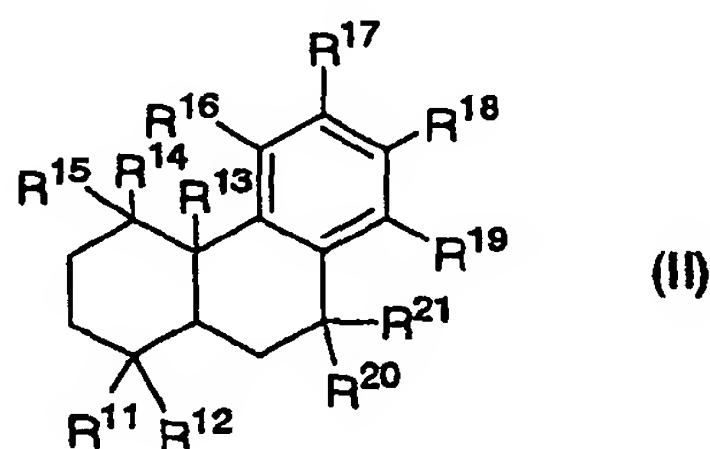


wherein  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$  and  $R^7$  are each  
 5 independently hydrogen, alkyl, alkenyl, halogen, hydroxy, halogenated alkyl, hydroxyalkyl, aminoalkyl, alkoxy, aryl, heteroaryl, acyl, carboxyl, alkoxycarbonyl, hydroxamate ( $-C(O)NHOH$ ), sulfo ( $-SO_3H$ ), carbamoyl ( $-CONH_2$ ), sulfonamide ( $-SO_2NH_2$ ), aldehyde or nitrile; or  $R^4$  and  $R^5$   
 10 may be bonded to each other to form a ring; or  $R^6$  and  $R^7$  may be bonded to each other to form a ring; and all of three bonds represented by --- are single bonds, or one of the three bonds is double bond and the other bonds are single bonds,  
 15 or a physiologically acceptable salt thereof as an active ingredient.

As a preferred embodiment of the present invention, provided is the above mentioned potassium channel opener comprising as an effective ingredient a compound wherein  $R^1$ ,  
 20  $R^3$ ,  $R^4$  and  $R^5$  are alkyl or alkenyl,  $R^6$  and  $R^7$  are hydrogen, and  $R^2$  is carboxyl, or a physiologically acceptable salt thereof. As a more preferred embodiment, provided is the above mentioned potassium channel opener comprising as an effective ingredient a substance selected from the group  
 25 consisting of the following compounds: (1) a compound wherein  $R^1$  is alkyl,  $R^2$  is carboxyl,  $R^3$  is alkyl,  $R^4$  is alkenyl,  $R^5$  is alkyl, and  $R^6$  and  $R^7$  are hydrogen (2) a compound wherein  $R^1$  is alkyl,  $R^2$  is carboxyl,  $R^3$  is alkyl,  $R^4$  is alkyl,  $R^5$  is alkenyl, and  $R^6$  and  $R^7$  are hydrogen, and (3) a compound wherein  $R^1$  is  
 30 alkyl,  $R^2$  is carboxyl,  $R^3$  is alkyl,  $R^4$  is alkyl,  $R^5$  is alkyl, and  $R^6$  and  $R^7$  are hydrogen, and a physiologically acceptable

salt thereof. And as a further preferred embodiment, provided is the above mentioned potassium channel opener comprising as an effective ingredient a substance selected from the group consisting of pimaric acid, dihydropimaric acid, dihydro-  
 5 isopimarinol, sandaracopimaric acid, isopimaric acid, and dihydroisopimaric acid, and a physiologically acceptable salt thereof.

Further, the present invention provides a potassium channel opener comprising a compound represented by the  
 10 following formula (II):



wherein  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$  and  $R^{21}$  are each independently hydrogen, alkyl, alkenyl, halogen, hydroxy, halogenated alkyl, hydroxyalkyl, aminoalkyl,  
 15 alkoxy, aryl, heteroaryl, acyl, carboxyl, alkoxycarbonyl, hydroxamate, sulfo, carbamoyl, sulfonamide, aldehyde or nitrile; or  $R^{20}$  and  $R^{21}$  may be bonded to each other to form oxo,

or a physiologically acceptable salt thereof as an active  
 20 ingredient.

As a preferred embodiment of the present invention, provided is the above mentioned potassium channel opener comprising as an effective ingredient a compound wherein  $R^{11}$ ,  $R^{13}$  and  $R^{18}$  are alkyls,  $R^{12}$  is carboxyl, and  $R^{14}$ ,  $R^{15}$  and  $R^{16}$  are  
 25 hydrogen, or a physiologically acceptable salt thereof. As a more preferred embodiment, provided is the above mentioned potassium channel opener comprising as an effective ingredient a compound wherein  $R^{11}$ ,  $R^{13}$  and  $R^{18}$  are alkyls,  $R^{12}$  is carboxyl,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{20}$  and  $R^{21}$  are hydrogen, and  $R^{17}$  and  
 30  $R^{19}$  are halogen or a physiologically acceptable salt thereof.

The above mentioned potassium channel opener provided

by the present invention is preferably a calcium-activated potassium channel opener, and may be used for prevention and/or treatment of, for example, essential hypertension, tonic bladder, airway hyperresponsiveness, or ischemic  
5 central nervous system disorder.

From another point of view, the present invention provides a use of the compound represented by the above formula (I) or formula (II) or physiologically acceptable salt thereof for preparation of the above potassium channel  
10 opener; a method for prevention and/or treatment of essential hypertension, tonic bladder, airway hyperresponsiveness, or ischemic central nervous system disorder, comprising a step of administering the compound of the above formula (I) or the formula (II) or a physiologically acceptable salt thereof, in  
15 an effective dose for prevention and/or a treatment to a mammal including a human; and a method of opening a potassium channel, preferably a calcium-activated potassium channel, comprising a step of administering an effective dose of the compound of the above formula (I) or the formula (II) or a  
20 physiologically acceptable salt thereof to a mammal including a human.

Further, there are provided a method for relaxing a smooth muscle in a mammal including a human, comprising a step of administering an effective dose of the above compound  
25 of the formula (I) or the formula (II) or a physiologically acceptable salt thereof to a mammal including a human; a method of protecting a central nervous system in a mammal including a human, comprising a step of administering an effective dose of the compound of the above formula (I) or  
30 the formula (II) or a physiologically acceptable salt thereof to a mammal including a human; a method of hyperpolarizing a smooth muscle cell in a mammal including a human, comprising a step of administering an effective dose of the compound of the above formula (I) or the formula (II) or a  
35 physiologically acceptable salt thereof to a mammal including a human; and a method of hyperpolarizing a neuron of a

central nervous system in a mammal including a human,  
 comprising a step of administering an effective dose of the  
 compound of the above formula (I) or the formula (II) or a  
 physiologically acceptable salt thereof to a mammal including  
 5 a human.

#### BRIEF DESCRIPTIONS OF THE DRAWINGS

Fig. 1 shows results of activation of BK $\alpha$  channels upon  
 10 administration of pimaric acid. The upper section and the  
 lower section show, respectively, a trace with a fast lapse  
 of time and a trace with a slow lapse of time.

Fig. 2 shows histograms of single BK $\alpha$  channel currents  
 (horizontal axis) before application of pimaric acid, after  
 15 application of 1 $\mu$ M, after application of 10 $\mu$ M, and after  
 washout, and their frequencies of events per unit time  
 (vertical axis). In the figure, CONTROL means results of  
 reference, 1 $\mu$ M means results of after application of 1 $\mu$ M,  
 10 $\mu$ M means results of after application of 10 $\mu$ M, and WASH OUT  
 20 means results of after washout.

Fig. 3 shows a relation between a concentration of  
 pimaric acid and an effect of BK $\alpha$  channel activation. The  
 vertical axis shows an opening probability (NPo), and the  
 horizontal axis shows a concentration of pimaric acid.

Fig. 4 shows a result of BK $\alpha\beta$ 1 channel activation by  
 25 administration of dichloridehydroabiatic acid as a  
 representative compound of the compounds represented by the  
 formula (II) (whole-cell current recording). In the figure,  
 A shows a periodical change accompanied by drug  
 30 administration, B shows original traces of currents at  
 respective points shown in the figure A, and C shows  
 concentration-effect relations in terms of BK ( $\alpha\beta$ 1) current  
 enhancing effect, for 3 kinds of test compounds. In the  
 figure C, o shows results of dichlorodehydroabiatic acid  
 35 (2Cl•DhA),  $\square$  shows results of abiatic acid (AbA), and  $\blacktriangle$   
 shows results of pimaric acid (PiA).



Fig. 5 shows a result of BK $\alpha$ 1 channel activation by administration of dichlorodehydroabiatic acid as a representative compound of the compounds represented by the formula (II) (single-channel current recording). In the figure, A shows results of observing changes in channel opening probability when the holding potential was maintained at +40 mV, B shows histograms of channel opening and closing events, obtained from original traces, and C shows a relation between concentration and effect.

Fig. 6 shows effects of pimaric acid (PiMA) and other compounds on macroscopic membrane currents in HEKBK $\alpha$ 1. In the figure A, single HEKBK $\alpha$ 1 cell was depolarized from -60 mV to +30 mV for 150 m second under whole-cell voltage clamp. Pimaric acid was applied cumulatively in a concentration range of 1 and 10  $\mu$ M. Original current recordings at different concentrations were shown in B. The peak outward current amplitude at +30 mV was measured and plotted against time. The original traces were obtained at the time indicated by vertical arrows in the time course. C shows the concentration-response relationships for 6 test compounds. Effects of pimaric acid ( $\square$ ), sandaracopimaric acid ( $\bullet$ ), isopimaric acid ( $\Delta$ ), dihydroisopimaric acid ( $\nabla$ ), dihydroisopimarinol( $\circ$ ), and abeitic acid ( $\blacksquare$ ) were examined in experiments identical to that shown in A for pimaric acid. The relative amplitude of peak outward current at +30 mV in the presence of test compounds ( $I_{\text{compound}} / I_{\text{control}}$ ) was determined taking the amplitude in the absence of them as unity (dotted line). Symbols and vertical bars show mean values and S.E.M., respectively; there were 4 to 5 experiments for each compound.

Fig. 7 shows effects of pimaric acid on the blockade of macroscopic currents by charybdotoxin (ChTX) in HEKBK $\alpha$ 1 cell. In the figure A, each single HEKBK $\alpha$ 1 cell was depolarized from -60 mV by 10 mV step for 150 msecond under whole-cell voltage clamp. Application of 10  $\mu$ M pimaric acid, and then 100 nM ChTX enhanced and then markedly reduced outward



currents, respectively. In the figure B, the current-voltage relationships were obtained in the control (●), in the presence of pimelic acid (◆), and after the further addition of 100 nM ChTX (□) in experiments such as illustrated in A. C shows the time course of effects of pimelic acid and ChTX on peak outward currents elicited by depolarization from -60 mV to +40 mV applied once every 15 seconds. ChTX was added cumulatively at concentrations of 3, 10, 30 and 100 nM in the presence of 10 μM pimelic acid. D shows the relationship between ChTX and the block of outward currents obtained from experiments shown in C. The relative amount of block was defined as the relative amplitude of current reduced by ChTX versus the amplitude before addition of ChTX in each cell in the absence (●), or presence (○) of 10 μM pimelic acid (n = 5 for each). The data were fitted with Hill equation modified for the concentration-block relationship. The fitted lines were drawn based on the following values of  $K_d$ , Hill coefficient and the constant; 7.66, 0.847 and 0.771 in the control and 6.72, 0.982 and 0.0965 in the presence of 10 μM pimelic acid, respectively.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The terms used in the present specification have the following meanings.

When "alkyl" is referred to, it means any form of straight, branched, cyclic, and a combination thereof. For example,  $C_1$ - $C_{12}$  alkyl, preferably  $C_1$ - $C_8$  alkyl, more preferably  $C_1$ - $C_6$  alkyl, and particularly preferably  $C_1$ - $C_4$  alkyl may be used. The alkyl moiety in the substituents having an alkyl moiety referred to in the present specification (e.g., alkenyl, halogenated alkyl, alkoxy, hydroxyalkyl, etc.) has the same meaning.

Positions and number of the double bonds contained in alkenyl are not particularly limited, and the number of the double bonds is preferably 1 to 3, more preferably 1 or 2,

and particularly preferably 1. As the alkenyl, preferred is allyl or vinyl and particularly preferred is vinyl. When geometric isomers arise based on the double bond, configuration of the double bond may either of Z or E.

5        "Halogen atom" (or "halogen") means any of fluorine atom, chlorine atom, bromine atom and iodine atom. Kind, number and substituting position of the halogen atom appearing on "halogenated alkyl" are not particularly limited, and the halogen atom may be any of fluorine atom, chlorine  
10 atom, bromine atom or iodine atom, and preferred is fluorine atom or chlorine atom. As the halogenated alkyl, for example, trihalogenated methyl is preferred and trifluoromethyl or trichloromethyl is particularly preferred.

Number and substituting position of hydroxy appearing  
15 on "hydroxyalkyl" are not particularly limited, and the number is preferably 1 to around 4, more preferably 1 or 2, and particularly preferably 1. As the hydroxyalkyl, for example, hydroxymethyl is preferred. Number and substituting position of amino appearing on "aminoalkyl" are not  
20 particularly limited, and the number is preferably 1 to around 4, more preferably 1 or 2, and particularly preferably 1. As the aminoalkyl, aminomethyl is preferred.

As the "aryl", it may be either of monocyclic or condensed aryl. For example, phenyl or naphthyl may be used.

25        "Heteroaryl" means, for example, heteroaryl containing 1 or 2 or more hetero atom(s) selected from the group of nitrogen, oxygen and sulfur as a ring constituting atom. As such examples, there may be mentioned pyridyl, furyl, thienyl or pyrrolyl. "Acyl" means either of arylcarbonyl such as  
30 benzoyl, or alkanoyl such as acetyl.

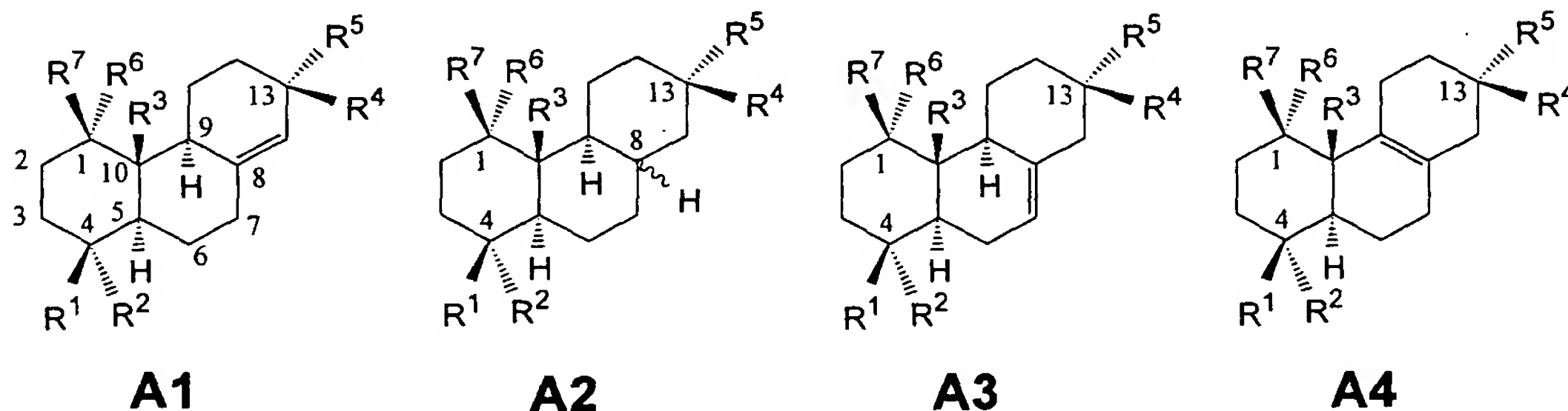
Alkyl, alkenyl, halogenated alkyl, hydroxyalkyl, alkoxy, aryl, heteroaryl, acyl, alkoxycarbonyl, hydroxamate, carbamoyl, or sulfonamide represented by  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$  and  $R^7$ , and  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$  and  $R^{21}$   
35 may further have one or two or more substituent(s). Kind, substituting position and number of the substituents are not

particularly limited, and when it has two or more substituents, they may be the same or different. For example, as a case where aryl has a substituent, there may be mentioned fluorophenyl, hydroxyphenyl, etc. and as a case  
 5 where acyl has a substituent, there may be mentioned chlorobenzoyl, trifluoroacetyl, etc., however, the examples of the substituents are not limited to these.

"Ring" formed by bonding  $R^4$  and  $R^5$ , or by bonding  $R^6$  and  $R^7$  is exemplified by  $C_3$ - $C_7$  cycloalkane ring such as  
 10 cyclopropane, cyclobutane, cyclopentane, cyclohexane and cycloheptane.

In the compounds represented by the above formula (I) or the formula (II), as shown in the present specification, when the stereochemistry of the compound is not shown, it  
 15 means the compound may be any stereoisomer, and pure form of any stereoisomer, any mixture of stereoisomers, racemates, a mixture of diastereoisomers and the like are included in the scope of the present invention.

As preferred examples of the compound represented by the formula (I), there may be mentioned the following  
 20 compound groups A1 to A4. Configurations in the following formulae A1 to A4 show the absolute configurations.

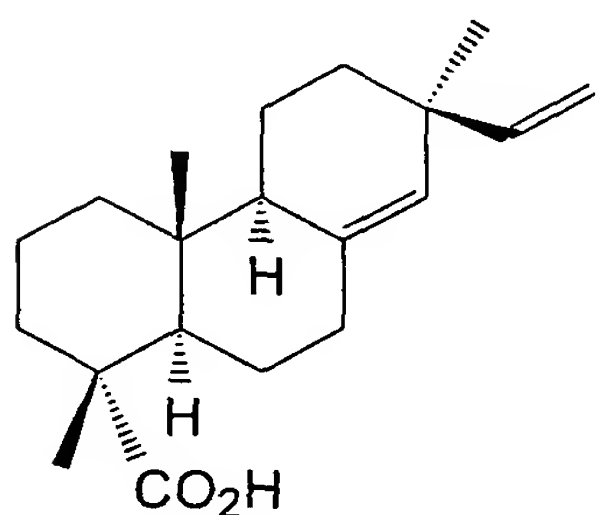


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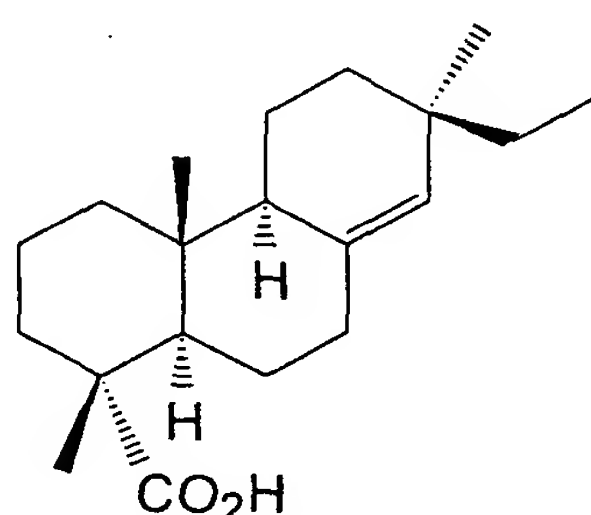
Preferably,  $R^1$ ,  $R^3$ ,  $R^4$ , and  $R^5$  are each independently alkyl or alkenyl. Preferred is a case where  $R^1$  is alkyl,  $R^3$  is alkyl,  $R^4$  is alkenyl and  $R^5$  is alkyl, or a case where  $R^1$  is alkyl,  $R^3$   
 30 is alkyl,  $R^4$  is alkyl and  $R^5$  is alkenyl. More preferred is a

case where  $R^1$  is methyl,  $R^3$  is methyl,  $R^4$  is vinyl or ethyl and  $R^5$  is methyl or a case where  $R^1$  is methyl,  $R^3$  is methyl,  $R^4$  is methyl and  $R^5$  is vinyl or ethyl.

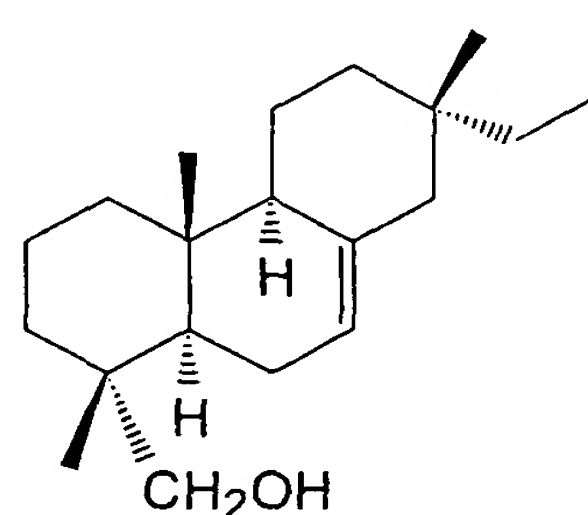
$R^2$  is preferably carboxyl, hydroxamate, sulfo, carbamoyl, sulfonamide, aldehyde, or nitrile, and more preferably carboxyl.  $R^6$  and  $R^7$  are both preferably hydrogen atoms. Particularly preferable compounds are the following compounds.



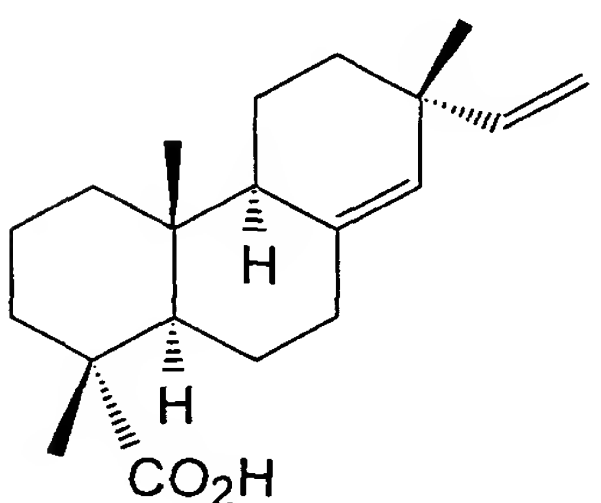
**Pimaric acid**



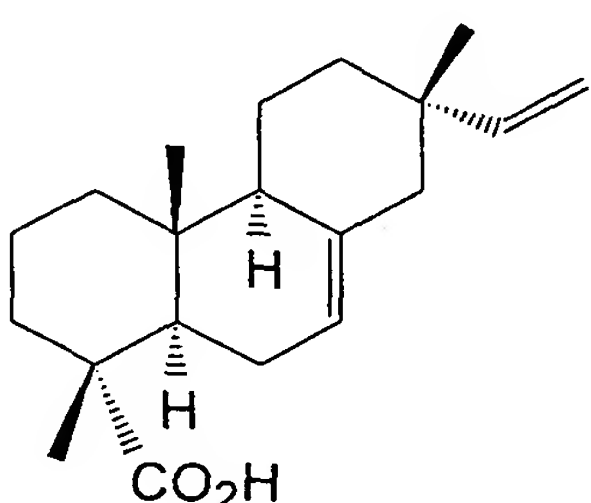
**Dihydropimaric acid**



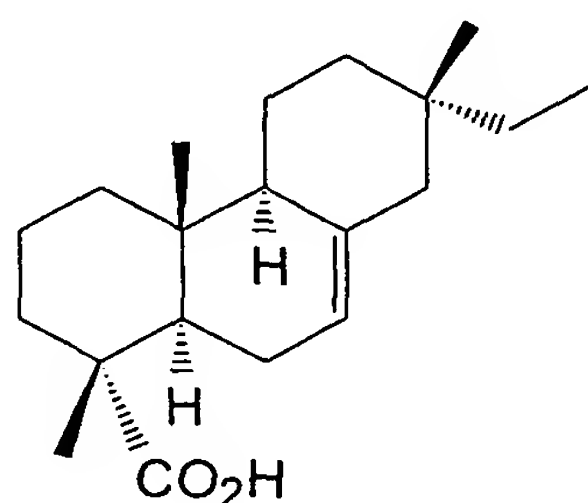
**Dihydroisopimarinol**



**Sandaracopimaric acid**



**Isopimaric acid**



**Dihydroisopimaric acid**

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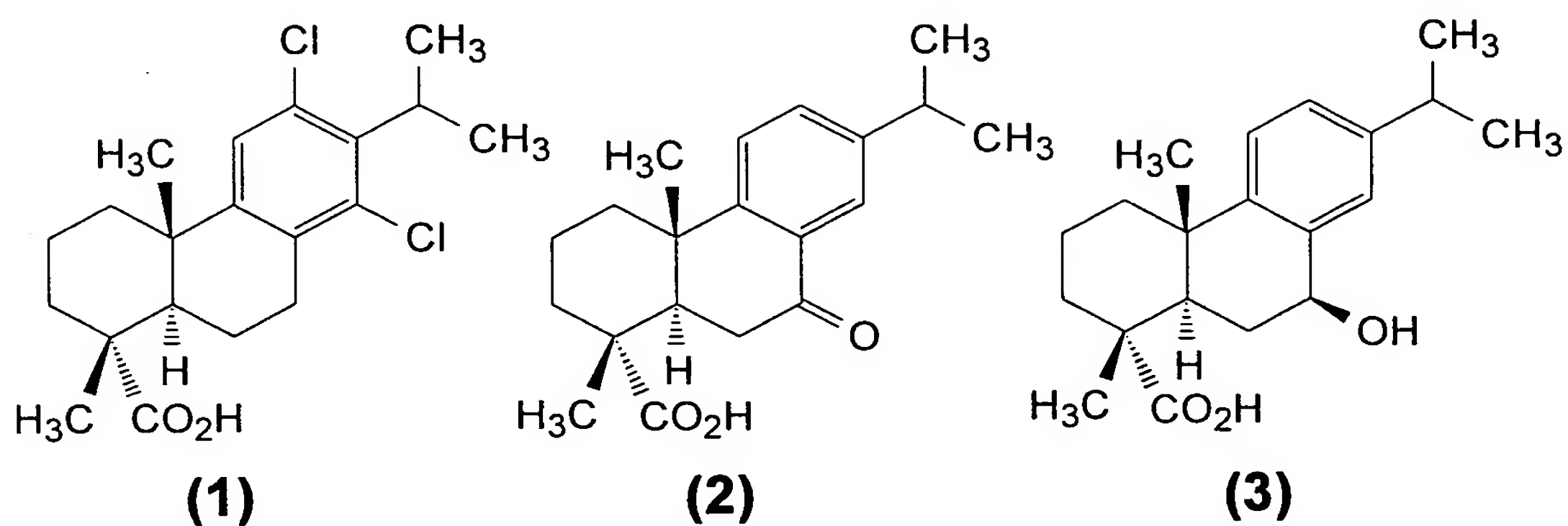
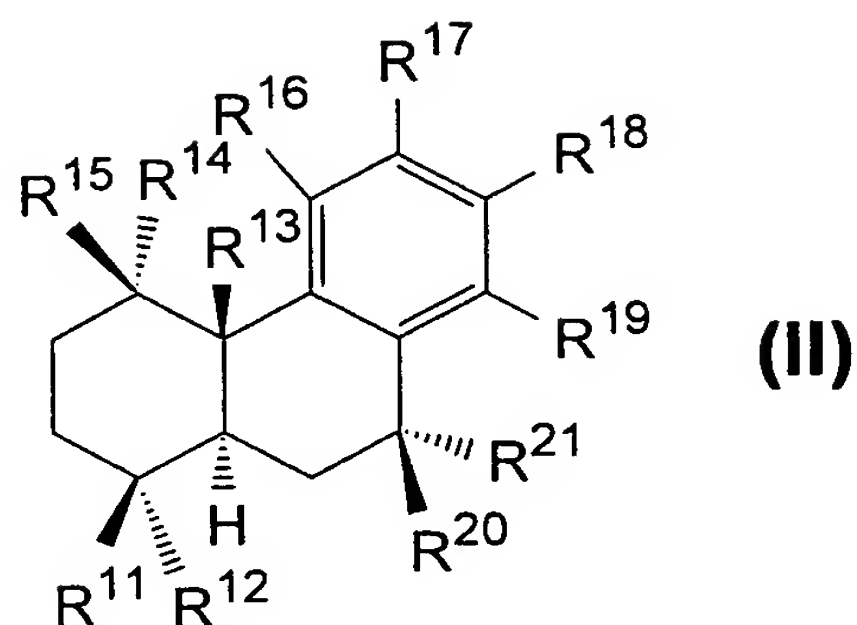
Among the particularly preferable compounds as shown above, pimaric acid is a known compound as a resin acid component. Further, sandaracopimaric acid, isopimaric acid, and dihydroisopimaric acid are commercially available. The compounds represented by the formula (I) may be prepared by, for example, using the above mentioned pimaric acid, dihydropimaric acid, sandaracopimaric acid, isopimaric acid, or dihydroisopimaric acid as a starting material, carrying out conversion of functional groups, which are conventionally

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known to the person skilled in the art. For example, dihydropimaric acid in which  $R^4$  is ethyl can be prepared by reducing vinyl existing as  $R^4$  in pimaric acid by a conventionally means, and a compound in which  $R^2$  is  
 5 alkoxyacetyl can be prepared by esterifying carboxyl existing as  $R^2$  in pimaric acid.

Further, in the compounds represented by the formula (II), preferred stereochemistry is as shown below (configurations in the formulae show absolute configurations),  
 10 and preferred is a case where  $R^{11}$ ,  $R^{13}$  and  $R^{18}$  are alkyls,  $R^{12}$  is carboxyl, and  $R^{14}$ ,  $R^{15}$  and  $R^{16}$  are hydrogen, and more preferred is a case where  $R^{11}$ ,  $R^{13}$  and  $R^{18}$  are alkyls,  $R^{12}$  is carboxyl,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{20}$  and  $R^{21}$  are hydrogen, and  $R^{17}$  and  $R^{19}$  are halogen. As the alkyl represented by  $R^{11}$  and  $R^{13}$ ,  
 15 methyl is preferred, and as the alkyl represented by  $R^{18}$ , ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, tert-butyl, etc. are preferred. As the alkyl represented by  $R^{18}$ , particularly preferred is isopropyl. As the halogen represented by  $R^{17}$  and  $R^{19}$ , preferred is chlorine.

20 Further, in the compounds represented by the formula (II), also preferred is a compound in which  $R^{20}$  is hydroxy, and  $R^{21}$  is a hydrogen atom, and a compound in which  $R^{20}$  and  $R^{21}$  are taken together to form oxo. For example, preferred is a compound in which  $R^{11}$ ,  $R^{13}$  and  $R^{18}$  are alkyls,  $R^{12}$  is carboxyl,  
 25  $R^{14}$ ,  $R^{15}$  and  $R^{16}$  are hydrogen,  $R^{17}$  and  $R^{19}$  are halogen or hydrogen,  $R^{20}$  is hydroxy, and  $R^{21}$  is hydrogen, and a compound in which  $R^{11}$ ,  $R^{13}$  and  $R^{18}$  are alkyls,  $R^{12}$  is carboxyl,  $R^{14}$ ,  $R^{15}$  and  $R^{16}$  are hydrogen,  $R^{17}$  and  $R^{19}$  are halogen or hydrogen, and  $R^{20}$  and  $R^{21}$  are taken together to form oxo. More specifically,  
 30 as preferred compounds of the formula (II), the following compounds may be exemplified, among which the compound represented by (1) is particularly preferred. All of the following compounds of (1) to (3) are commercially available.



As an active ingredient of the potassium channel opener of the present invention, besides the compounds represented by the above formula (I) or the formula (II), physiologically acceptable salts thereof depending on the kinds of substituents may be used. Kinds of the salts are not particularly limited as long as they are physiologically acceptable, and the salts may be either of acid addition salts or base addition salts. As the acid addition salt, there may be mentioned, for example, a mineral acid salt such as chloride, sulfate, nitrate, etc. and an organic salt such as p-toluenesulfonate, methanesulfonate, oxalate, maleate, tartrate, etc. And as the base addition salt, there may be mentioned a metal salt such as a sodium salt, a potassium salt, a calcium salt, etc. and an organic amine salt such as an ammonium salt, a triethylamine salt, an ethylamine salt, etc. Also, a salt with an amino acid such as glycine may be used.

As an active ingredient of the potassium channel opener



of the present invention, besides the compound in a free form and the physiologically acceptable salt thereof, any hydrates or solvates thereof may be used. There is no particular limitation to kinds of solvents to form the solvates, and for example, acetone, ethanol, tetrahydrofuran, etc. may be mentioned. Further, the compound of the above formula (I) or the formula (II) may further have one or more asymmetric carbons besides the asymmetric carbons contained in the above formulae, depending on kinds of substituents. Therefore, stereoisomers such as optically active isomers or diastereoisomers based on the asymmetric carbons may exist, and pure form of stereoisomers, any mixture of stereoisomers, racemates, etc. may be used as an active ingredient of the potassium channel opener of the present invention.

Although it is not our intension to be bound by any specific theory, the potassium channel opener of the present invention acts on calcium-activated potassium channel proteins being present in smooth muscle which are constituents of various kinds of organs, including blood vessel, bladder, bronchial tube, gastrointestinal tract, etc., and central or peripheral nervous system, and increases chance of opening of the respective calcium-activated potassium channels per unit time (opening probability), thereby increasing potassium permeability of cell membrane. This leads to hyperpolarization of smooth muscle cells and lowers activities of voltage-dependent potassium channels. And by inhibiting calcium influx from extracellular fluid, smooth muscle is relaxed and neuronal cells are protected from damages caused by calcium overload.

Therefore, the potassium channel opener of the present invention can relax smooth muscle tissues, which are constantly under contraction (hypertension) in pathological states such as hypertension including essential hypertension, tonic bladder, disturbances of peripheral circulation, airway hyperresponsiveness, sensory neuron hypersensitivity, central spasm, etc., and is useful as a medicament for preventing

and/or treating these diseases. Further, it is useful as a medicament for protecting neuronal cells of central or peripheral nervous system, particularly, neuronal cells of central nervous system. In spite of the above, an object of application of the potassium channel of the present invention is not limited to the above mentioned particular diseases, and it is applicable for various diseases which can be prevented and/or treated by relaxing smooth muscle, and various diseases which can be prevented and/or treated by protecting neuronal cells.

The potassium channel opener of the present invention may comprise one kind or two or more of the substances selected from the group consisting of the compounds of the above formula (I) and the formula (II) and physiologically acceptable salts thereof, and hydrates and solvates thereof.

As a medicament of the present invention, the above substances may be administered as they are, and preferably, they may be administered as a pharmaceutical composition for oral or parenteral administration, which can be prepared according to conventionally known methods for person skilled in the art. As the pharmaceutical composition suitable for oral administrations, tablets, capsules, powders, fine granules, granules, liquid, or syrup, etc. may be exemplified, and as the pharmaceutical composition suitable for parenteral administration, injections, infusions, suppositories, inhalants, eye drops, nasal drops, ear drops, ointment, cream, percutaneous absorbents, permucosal absorbents, adhesive plaster, etc. may be exemplified.

One kind or two or more of formulation additives may be added to prepare the above pharmaceutical compositions. As the formulation additives, excipients, disintegrators or disintegrating aids, binders, lubricants, coating agents, pigments, diluents, bases, solvents or solubilizing aids, isotonic agents, pH buffers, stabilizer, propellants, adhesives, etc. may be exemplified. They may be optionally selected depending on the forms of the pharmaceutical

compositions.

The dose of the potassium channel opener of the present invention is not particularly limited, and it is optionally selected depending on kinds of actions and strength of the actions, and it may be optionally adjusted depending on various factors to be generally considered, including weights or ages of the patients, kinds and conditions of diseases, and its administration route. Generally, in case of oral administration, it can be used in a range of 0.01 to 1,000 mg, per an adult per day.

#### EXAMPLES

In the following, the present invention is explained in more detail by referring to Examples, however, the present invention is not limited by these Examples. Pimaric acid used in Examples were purchased from ICN, Inc. of the United States.

##### Example 1

##### (A) Experimental System

Calcium-activated potassium channel (hereinafter abbreviated as "BK channel" in Examples) functions with two kinds of proteins  $\alpha$  (BK $\alpha$ ) and  $\beta$  (BK $\beta$ ) subunits being arranged in tetramers. BK $\alpha$  consists a main part of a channel and BK $\beta$  is an activity regulating factor. In order to selectively detect BK channel opening effect, BK channels were artificially expressed on cultured cells which do not originally have the BK channels (cultured cells derived from human embryonic kidney, HEK293 cells) by gene transfection, to constitute an experimental system. In accordance with a method of Ahring, et al. (Ahring P.K., et al., FEBS Lett., 415, pp.67-70, 1997), cDNAs of BK $\alpha$  and BK $\beta$ 1 genes derived from rat uterus smooth muscle (GenBank accession numbers; U55995 and AF020712) were introduced into HEK293 cells by using calcium phosphate coprecipitation transfection techniques, to constantly overexpress BK $\alpha$  or BK $\alpha\beta$ .

## (B) Methods and Results

## (a) Single channel current recording by Inside-out patch clamp technique

By using Inside-out patch clamp technique, fragments of  
 5 cell membrane containing the channels were isolated, and by  
 artificially controlling an environment of inside of the cell  
 membrane, opening or closing of a single channel can be  
 directly observed. This is a fully established method not  
 only for functional analysis of the channel, but also for  
 10 testing quantitative effects of the channel agonists (Hamil,  
 O.P., et al., Pflgers Archiv., 391, pp.85-100, 1981). BK $\alpha$   
 and BK $\alpha\beta$  expressed on HEK293 cells that were used in the  
 present measurement, both showed single channel conductance  
 of 230-240 pS when solutions inside and outside of the patch  
 15 membrane contains 140mM K, and they were confirmed to have  
 properties which correspond well to those in the prior  
 literatures.

Under this condition, action and effect of pimaric acid  
 for BK $\alpha$  was measured. The upper section of Fig. 1 shows BK $\alpha$   
 20 single channel recording when the patch membrane potential is  
 kept so that inside of the cell is +40 mV relative to the  
 outside of the cell, and intercellular Ca concentration is  
 0.1 $\mu$ M (the upper section: upward rectangles show currents due  
 to channel openings). When pimaric acid was added to the  
 25 solution of the inner side of the cell membrane, at a  
 concentration of 10  $\mu$ M or less, channel activity is  
 significantly increased (the middle section), and the action  
 disappeared when pimaric acid was washed away.

Fig. 2 shows results of carrying out such current  
 30 recordings for 30 seconds, as histograms. In Current  
 Amplitude, 0 pA means a closing state. Addition of pimaric  
 acid at a concentration of 1  $\mu$ M or 10  $\mu$ M increased time of an  
 opening state, and particularly, in case of 10  $\mu$ M, it was  
 shown that there were cases where two channels simultaneously  
 35 opened. In Fig. 3, a relation between a concentration of  
 pimaric acid and an effect of BK channel activation is shown

under this condition. By addition of pimaric acid at concentration of 3  $\mu\text{M}$  or more, a significant increase in channel opening probability was confirmed. Further, when Ca concentration of the inner side of the cell membrane is 0.3  $\mu\text{M}$ , and the patch membrane potential is +40 mV, the opening probability at 1  $\mu\text{M}$  increased by three times.

(b) Membrane current recording by Whole cell voltage-clamp technique

Membrane current of the whole cell by opening of BK $\alpha$  channels was recorded by Whole cell voltage-clamp technique. This technique is frequently employed to analyze the functions shown by the ion channels expressed in numbers on a cell membrane as a whole, and is a well established technique (Hamil, O.P. the above mentioned reference). When this technique was applied to a single HEK293 cell on which BK $\alpha$  channels were expressed, 1 $\mu\text{M}$  of pimaric acid added to extracellular fluid increased BK $\alpha$  current by about 50% at +60mV, showing a significant channel opening action. Since the action of pimaric acid was completely inhibited by addition of 1mM tetraethylammonium, which is a BK channel inhibitor, it was confirmed that the action of pimaric acid was an opening of BK channel.

From the above results, it was shown that Pimaric acid acts on BK $\alpha$ , exhibiting BK channel opening effect and that the action was exhibited by administration of Pimaric acid to extracellular fluid, and it was removed immediately by washout, and the effect was at least three times or more as much as the effect of maxikdiol described in the reference. It is thought to have an effect of 10 times or more as much as that of NS-1619, which is a known compound which is known to have a BK channel opening effect. From these results, it can be concluded that Pimaric acid is extremely useful as a BK channel opener.

## Example 2

As a compound represented by the formula (II), the

above shown compound (1) (dichlorodehydroabietic acid) was used to analyze BK channel opening effect.

(1) Material and method

(a) Whole cell current recording

5        According to the whole-cell patch clamp technique, whole-cell currents were recorded on HEK293 cell, in which rat BK $\alpha$  +  $\beta$ 1 subunits were constantly expressed. All the experiments were carried out at 22-24°C.

Solution:

10    Pipette solution (mM) 140 KCl, 4 MgCl<sub>2</sub>, 5 ATP, 10 HEPES, 5 EGTA (the pCa was adjusted to 6.5 by adding a suitable amount of CaCl<sub>2</sub> to stabilize the pCa). The pH was adjusted to 7.2 with KOH.

Extracellular fluid (mM) 137 NaCl, 5.9 KCl, 2.2 CaCl<sub>2</sub>, 1.2  
15    MgCl<sub>2</sub>, 14 Glucose, 10 HEPES. The pH was adjusted to 7.4 with NaOH.

(b) Single-channel recording

      According to the inside-out patch clamp technique, a single channel current was recorded on HEK293, in which rat  
20    BK $\alpha$  +  $\beta$ 1 subunits were constantly expressed. All the experiments were carried out at 22-24°C.

Solution:

Intracellular fluid (mM) 140 KCl, 1.2 MgCl<sub>2</sub>, 14 Glucose, 5  
EGTA (the pCa was adjusted to 7 by adding a suitable amount  
25    of CaCl<sub>2</sub> to stabilize the pCa). The pH was adjusted to 7.2 with NaOH.

Extracellular fluid (mM) 140 KCl, 4 MgCl<sub>2</sub>, 5 ATP, 10 HEPES, 0.05 EGTA. The pH was adjusted to 7.2 with KOH.

      Since the test compounds were highly aliphatic, and  
30    hard to dissolve in water, they were dissolved by DMSO and preserved as 30 mM stock solutions. On administration, final concentration in the DMSO solutions were made at most 0.03%. Incidentally, DMSO was confirmed not to have any influence on BK currents, when its concentration is 0.3% or less.

35

(2) Results



The whole-cell currents were recorded with the cells in which BK( $\alpha$ + $\beta$ 1) channels were constantly expressed, by the whole-cell patch clamp technique. The  $\text{Ca}^{2+}$  concentration in the intracellular fluid was fixed at pCa 6.5 with  $\text{Ca}^{2+}$ -EGTA buffer. The pulse depolarizing from the resting potential - 60 mV to +10 mV, was added for 150 mseconds, and the elicited currents were observed. By the depolarizing stimulus, moderately activated outward currents were observed, which are characteristic of BK( $\alpha$ + $\beta$ 1) channel (control in Fig.4B).

After establishing the whole cell, the recording was started at a point where stable current measurements were obtained for 20 minutes. When 100nM of the test compound was applied, the currents were enhanced in course of time, and as the concentration of the test compounds increases, the currents were observed to become larger correspondingly. After that, by washout, the current went back almost to the level prior to application of the test compounds (Fig. 4A). As a result of a statistical analysis based on the recordings of the 4 examples, the currents were activated by  $1.90 \pm 0.21$  times at concentration of 100 nM,  $2.54 \pm 0.14$  times at 300 nM, and  $6.37 \pm 0.91$  times at 1  $\mu\text{M}$ , by this activating effect. As compared to the fact that pimelic acid activated the current by  $1.92 \pm 0.24$  times at 1  $\mu\text{M}$ , it was shown to have a clearly stronger effect (Fig. 4C).

BK channels are activated by increase in the intercellular  $\text{Ca}^{2+}$  concentration. Therefore, if the test compound has an effect of increasing the intracellular  $\text{Ca}^{2+}$  concentration, the channel activation may be caused thereby. In this connection, on the whole-cell recordings, 5 mM EGTA and  $\text{CaCl}_2$  were added into the pipette solution to buffer the intercellular  $\text{Ca}^{2+}$  concentration to proximity of pCa 6.5, thereby excluding most of the influences.

In order to further confirm this point, a single channel current recording was carried out. The single channel current was recorded with respect to the cells in which BK( $\alpha$ + $\beta$ 1) channels were constantly expressed, by the

inside-out patch clamp technique. The intracellular fluid (the fluid contacting the inner side of the cell membrane) was fixed at pCa 7.0. Holding potential was maintained at +40 mV, and a change in channel opening probability was observed. When the test compound was applied to the inner side of the cell membrane, channel activation was observed at concentration of 100 nM or more, and the effect was removed by washout (Fig. 5A). From the original traces, histograms of the opening and closing events were prepared. Accompanied by application of the test compounds, the peak of approximately 10 pA increased, which shows an opening of the channel, and this effect was removed by washout (Fig. 5B). From these histograms, channel opening probability was calculated to show relation between the concentration and effect as shown in Fig. 5C. From this result, it was shown that the effect of the test compound was concentration-dependent.

### Example 3

#### 20 (Method and results)

Effects of test compounds on BK channel currents were examined in single HEK293 cell expressing BK( $\alpha$ + $\beta$ 1) channels (hereinafter referred to as HEKBK $\alpha\beta$ 1) under whole-cell voltage clamp. The Ca<sup>2+</sup> concentration in the pipette solution was fixed at pCa 6.5 using a Ca<sup>2+</sup>-EGTA buffer. Depolarization from -60 mV to +30 mV induced outward currents in both native HEK293 and HEKBK $\alpha\beta$ 1, but the current density was much higher in the latter (the current density at the peak:  $11.0 \pm 1.8$  and  $95.2 \pm 20.9$  pA/pF, n=5 and 6, respectively, p<0.05). Application of pimaric acid in a concentration range of 1 to 10  $\mu$ M increased outward currents in a dose-dependent fashion in HEKBK $\alpha\beta$ 1 (Fig. 6A), but did not change in native HEK293 (data not shown). This enhancement of outward current by pimaric acid could be removed completely by washout. Effects of other test compounds were also examined in this manner. The peak

amplitude of outward current at +40 mV in the presence of 1, 3, and 10  $\mu$ M resin acids was measured relative to the value taken just before the application (Fig. 6B). Pimaric Acid, sandaracopimaric acid, isopimaric acid, dihydroisopimaric acid, and dihydroisopimarinol showed significant potentiating effects on outward current at concentration of 1  $\mu$ M and higher ( $n = 4-5$ ,  $p < 0.05$  versus 1.0).

To determine whether pimaric acid changes the binding of charybdotoxin (ChTX) to BK channels, the concentration-dependent block of macroscopic currents by ChTX was measured in HEK BK $\alpha\beta$ 1, in the absence and presence of 10  $\mu$ M pimaric acid (Fig. 7). The outward currents elicited by depolarization from -60 mV in 10 mV steps were enhanced at potentials positive to -20 mV. The current at +40 mV was increased from  $1214 \pm 153$  to  $2527 \pm 448$  pA ( $n = 5$ ,  $p < 0.05$ ). The addition of 100 nM ChTX significantly reduced the outward current to levels lower than those under the control conditions (Fig. 7, A and B). The remaining components in the presence of 100 nM ChTX include native delayed rectifier  $K^+$  currents and unblocked BK $\alpha\beta$ 1. The currents at +40 mV in the presence of 10  $\mu$ M pimaric acid was reduced from  $2527 \pm 448$  pA to  $499 \pm 90$  pA ( $p < 0.01$  versus before the application of and in the presence of 10  $\mu$ M pimaric acid). Cumulative addition of ChTX in the range of 3 to 100 nM reduced outward current in a concentration dependent manner (Fig. 7C). A concentration-response relationship for ChTX-induced block was also obtained in the absence of pimaric acid; the current amplitude at +40 mV was reduced from  $1233 \pm 226$  to  $205 \pm 46$  pA by addition of 100 nM ChTX ( $n = 5$ ,  $p < 0.01$ ). The normalized data were well fitted with the Hill equation modified for the concentration-response relationship.  $I_{block} = (1-C)/\{1+(K_d/[ChTX])^{n_H}\}$ , where  $K_d$  is the apparent dissociation constant of ChTX,  $[ChTX]$  is the concentration of ChTX,  $n_H$  is the Hill coefficient, and  $C$  is the constant. The  $K_d$  obtained from the best fitting were  $7.66 \pm 2.66$  and  $6.72 \pm 2.26$  nM ( $n = 5$ ,  $p > 0.05$ ), in the absence and presence of pimaric acid,

respectively. The  $n_H$  value,  $0.847 \pm 0.034$  and  $0.982 \pm 0.161$  ( $p > 0.05$ ), respectively, suggest one-to-one binding of ChTX to BK $\alpha\beta$ 1. The C values which may correspond to the native K<sup>+</sup> currents insensitive to ChTX, were  $0.077 \pm 0.0226$  and  $0.0965 \pm 0.0388$  ( $p > 0.05$ ), respectively. The data in Fig. 7D show that the relationship in the presence of 10  $\mu$ M pimaric acid was almost identical with that in its absence. The half-maximum concentrations of ChTX for the block of BK channel current were almost identical each other in the absence and presence of pimaric acid (7.66 and 6.72 nM). These results suggest that pimaric acid does not affect the binding of ChTX to BK channels.

#### 15 Industrial Applicability

Since the medicament of the present invention has an excellent potassium channel opening effect, and further its effect is specific, it is useful for prevention and/or treatment of essential hypertension, tonic bladder, airway hyperresponsiveness, or ischemic central nervous system disorder.